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The Role of Human Causal Factors in U.S. Army Unmanned Aerial Vehicle Accidents

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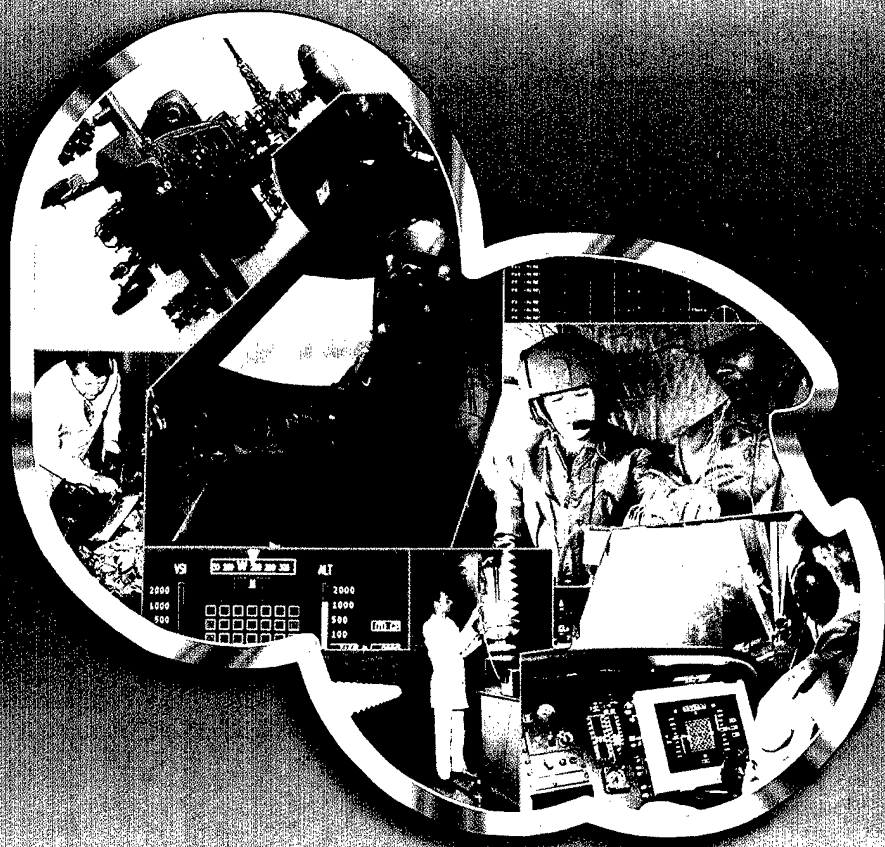

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13. ABSTRACT *(Maximum 200 words)*
For the period FY95-FY03, each Unmanned Aerial Vehicle (UAV) accident was reviewed and classified by a series of characteristics using two approaches. The first was a variant on a methodology referred to as the Human Factors Analysis and Classification System (HFACS). The HFACS captures data for four levels of human-related failure: Unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. The second analysis approach was based on the accident methodology defined in Department of the Army Pamphlet 385-40, "Army accident investigation and reporting." Human causal factors are identified during this analysis and broken down into five types of failure: Individual failure, leader failure, training failure, support failure, and standards failure. Where the assignment of cause included human error, the accident data including narrative and findings were analyzed to identify specific human causal factors (e.g., high/low workload, fatigue, poor crew coordination, etc.). No single human causal factor was responsible for all accidents. However, both methods of analysis identified individual unsafe acts or failures as the most common human-related causal factor category (present in approximately 61 percent of the 18 human error related accidents).

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Table of contents

Table of contents (continued)

List of figures

List of tables

Introduction

Unmanned aerial vehicles (UAVs) are autonomous or remotely piloted aircraft platforms that carry various payloads, e.g., cameras, sensors, communications equipment, munitions, etc. Currently, all of the U.S. military services, Navy, Army, Air Force, and Marines, field UAV systems. Approximately 200 UAVs of all types are in the combined military inventory (Garamone, 2002). The U.S. Air Force's Predator, also employed by the Central Intelligence Agency, is probably the most widely recognized UAV. The expanded use of the Predator and other UAVs in Afghanistan and Iraq has brought UAVs into the public spotlight.

Information dominance has always been the key to controlling the battlefield; however, timely access to real-time battle information has generally been unavailable. UAVs finally can provide commanders with near instantaneous knowledge of battlefield conditions and they can remain "on station" for several days at a time (Petrie, 2001). While military satellites are able to provide some information of a similar nature, their space-to-earth transmissions, like all wireless broadcasts, are vulnerable to interception. In extremely sensitive operations, UAVs can photograph areas, be flown back to base where the photos can be analyzed, and so are more secure to the extent that they are not sending out transmissions that the enemy can intercept.

Advocates for UAVs cite a number of distinct advantages over manned aircraft. These advantages include reducing or eliminating human loss; lowering initial system development cost; lowering replacement cost; lowering operator training investment; expanding mission time; reducing detection signature and vulnerability; being able to operate in nuclear, chemical and/or biological environments, and reducing peacetime support and maintenance costs (Carlson, 2001).

While UAVs offer multiple advantages, they do have a few disadvantages. Many are slow and low flying, making them easy targets for enemy ground forces. Remotely piloted UAVs require a complex and highly reliable communication link to the control station (Mouloua et al., 2001a). While automating some functions within a UAV control system may overcome certain remote operation disadvantages, removing the man from the cockpit reduces the ability to make rapid decisions with the maximum situational awareness. In general, computers are best at calculations and humans are best at decision-making (Hancock and Scallen, 1996).

UAVs can be described as small-scale aircraft, in design and operation. They range in size from less than 10 to hundreds of feet in length with wingspans up to several hundred feet. Payload capability currently approaches one ton with flight times as high as 48 hours and a maximum altitude capability in excess of 60,000 feet (Larm, 1996). These operating parameters are constantly increasing.

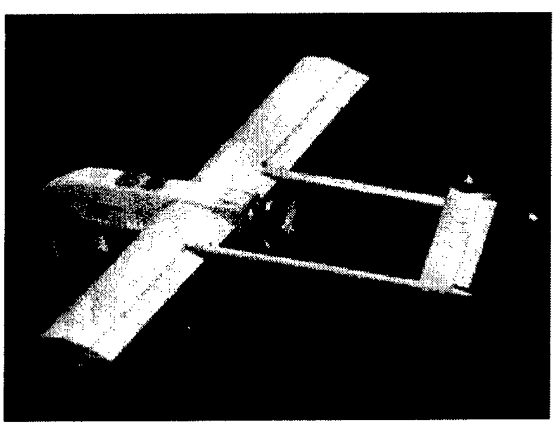
UAVs can be of two types: autonomous or remotely piloted. Autonomous UAVs fly and perform mission profiles under the control of a computer software program. With autonomous UAVs, specialists program an onboard computer that controls the aircraft flight from point-to-point. The UAV may take off and lands itself. While humans oversee the programming and tell the UAV where to go, it's the onboard computer that actually controls the air vehicle in flight (Garamone, 2002).

A basic remotely piloted UAV system consists of three fundamental elements: an aerial platform (the UAV itself), a ground control station, and a crew. A typical UAV crew consists of three personnel, usually designated as the air vehicle operator, external pilot, and mission payload operator (Barnes et al., 2000). The external pilot "flies" the UAV during takeoffs and landings. The air vehicle operator monitors the UAV's progress between way points, making any necessary adjustments as it flies to and from the target area. The mission payload operator executes the search pattern within the target area. Today, most UAVs are a blend of both the autonomous and remote systems.

The U.S. Army currently fields two major UAV systems: the RQ-7 Shadow and the RQ-5 Hunter (Figure 1). The Shadow 200 is a small (9 feet in length), lightweight (330 pounds), short-range surveillance UAV that is used by ground commanders for day/night reconnaissance, surveillance, target acquisition, and battle damage assessment. Capable of operating at altitudes of 14,000 feet, the Shadow can carry instrument payloads of up to 60 pounds. The Hunter is a twin-engine, short-range tactical UAV, providing capability for an increased payload (200 pounds), and endurance period (up to 12 hours). It weighs 1600 pounds and has a 29-foot wingspan (Riebeling, 2002).

Both systems are remotely piloted. However, the Shadow uses a launcher rather than a runway for takeoffs. It uses an automatic landing system with arresting gear for landings, similar to that used on aircraft carriers. U.S. Army UAV systems use two-man teams at the ground control system, an air vehicle operator who flies the UAV and a mission payload operator who controls the camera and other sensors (Harding, 2003). Operating characteristics for these two systems are summarized in Table 1.

The U.S. Army has several other UAV developmental programs for systems that will be able to operate up to 200 miles in range and 25,000 feet in altitude (Riebeling, 2002). In addition, there are several UAV types that have seen limited usage or are used for training. These include the MQM-34D Firebee and the short-range Pioneer.



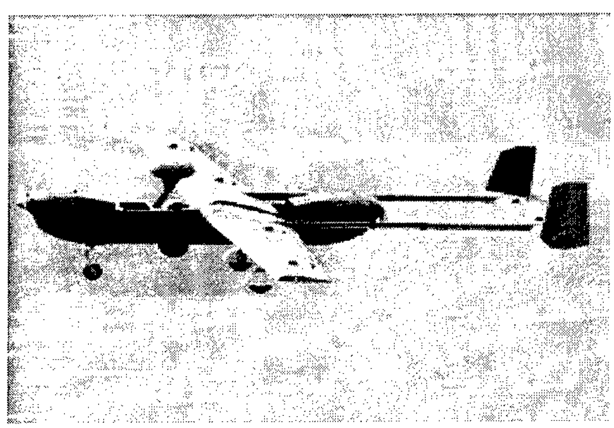


Figure 1. Photographs of U.S. Army UAVs, the Shadow 200 (left) and the Hunter (right).

Table 1.
Characteristics of U.S. Army UAVs (Global Security, 2003; Riebeling, 2000).

Characteristic	Shadow 200	Hunter
Wing span	13 feet	29 feet
Range	125 km	>200 km
Airspeed	90 knots	90 knots
Altitude	14,000 feet	15,000 feet
Endurance	4-5 hours	8-12 hours
Payload	60 pounds	200 pounds

Use of UAVs by the military seems to be a growing trend for two major reasons. The first reason is economics. With concerns about a decreasing budget, the advantages of UAVs presented above will result in long-term savings over manned aircraft. These savings can be associated with initial design costs, crew training, and support logistics. The second reason is politics. Today's real-time reporting of battlefront casualties, an unfortunate but undeniable consequence of war, is unsettling to the public and becomes a political liability. In order to sustain an ever-increasing role of UAVs and a declining role of manned aircraft, UAVs must be at least equally successful in meeting mission requirements. They must also have an acceptable accident rate in order to be cost-effective.

Problem Statement

UAVs, while having been under development and having seen limited use for several decades, are finally and rapidly coming into their own as major tactical and strategic systems on the modern battlefield. This rapid increase in use has been accompanied by an increased frequency of accidents. While UAVs share inherent characteristics with aircraft, UAV accidents differ fundamentally from aviation accidents and are currently treated as ground accidents within the Army. Aviation and ground accidents have three major causes: Human, materiel, and environmental factors. Human-related factors are the most common. To date there have been few, if any, studies investigating the role of human causal factors associated with Army UAV accidents. Knowledge of these human-related causal factors is necessary to reduce costs and increase mission effectiveness.

Purpose

The purpose of this study was to investigate U.S. Army UAV accidents, analyzing each accident for causal factors and identifying those that were related to human errors. Identifying these factors may point to changes in operational doctrine that can decrease accident costs and increase mission effectiveness.

Research questions

What are the human-related causal factors of U.S. Army UAV accidents? What patterns exist, if any, and how can the discovery of such patterns lead to doctrine and training strategies that can reduce the frequency of accidents in which human error is a contributing factor?

Significance

Accidents cost financial resources and mission effectiveness. Understanding human error causal factors can reduce accident frequency and rate. Performing an analysis of the role of human causal factors in UAV accidents will aid in identifying design and training deficiencies.

Assumptions

The validity of the proposed study, its findings, and the successful application of these findings to reduce human error related accidents are based on three assumptions. The first is that data obtained from the U.S. Army Safety Center's (USASC) accident database are accurate and complete. The second is that the accident data to date are representative of current and future UAV accidents. The last is that resources will be available to implement the recommendations resulting from the study.

Limitations

This study was limited to all reported accidents currently in the USASC's accident database for the period FY95-FY03, based on data entries made by 12 February 2003. It is quite possible that due to the previous security classification of UAVs, all accidents may not be available for analysis.

Two caveats must be applied to the causal factor analysis approaches used in this study. First, the assignment of causal factor categories/subcategories was somewhat subjective in nature and based on the author's interpretation. While the authors have been involved with the accident investigation field for some time, other researchers might come to different conclusions regarding assignment of causal factors. However, the distributions of causal factors reported should be considered near approximations. Second, the assignment of categories/subcategories for some accidents was limited by the incompleteness of the accident report and the amount of detail in the data provided.

Literature review

UAV accidents

Knowledge of UAV losses, either due to accidents or enemy fire, is naturally a sensitive nature. Very few statistics are available in the open literature. However, the available data point to a higher accident rate for UAVs over manned aircraft.

Since 1994, the U.S. Air Force has reported losing half of its R-1 Predator fleet due to crashes or enemy fire; however, most of the crashes occurred during testing (Cable News Network, 2002). In 1999, the U.S. Navy and U.S. Marine Corps, acknowledging an "unacceptable" UAV accident rate, attributed half of the accidents in part to human factor causes (Ferguson, 1999). As of 2001, UAVs represented a miniscule 0.6 percent of the Department of Defense military aircraft fleet. The ratio of manned to unmanned flight hours was 300 to 1. However, UAVs suffered an accident rate of 10 to 100 times that of manned aircraft (Department of Defense, 2001).

Israel has the most experience with UAV design, operation, and losses. In April 2001, the Israelis released a study of their UAV accidents based on 80,000 flight hours. The U.S. had correspondingly accumulated approximately 50,000 flight hours. The study attributed 75 percent of accidents to propulsion, flight control systems, and operator error. Operator error, as a causal factor, was present in approximately 20 percent of all accidents (Department of Defense, 2001).

It is difficult to determine any exact accident rates for UAVs based on the above information. However, there does appear to be a significant enough number of UAV accidents to warrant investigation of causal factors, for the purpose of reducing equipment losses.

Human error in accidents

The Army identifies three major causes of accidents: Human, materiel, and environmental factors. Human causal factors relate to human errors, which are mainly those inherent to human design, function and behavior. Materiel factors include equipment failure and damage that can result from design flaws, component or system failure, etc., such that a component or system becomes inoperable. Environmental factors include noise, illumination, and weather conditions (e.g., precipitation, temperature, humidity, pressure, wind, and lightning, etc.), which can adversely affect the performance of the individual or equipment (Department of the Army, 1994a). Causal factors related to human error are the most frequently cited in accidents. Studies have implicated human error in accidents across virtually all occupations, with 70% to 80% involvement for civil and military aviation (O'Hare et. Al, 1994; Shappell and Wiegmann, 2001; Yacavone, 1993; Wiegmann and Shappell, 1999; 2001). Additional work has shown that while the aviation accident rate attributable entirely to mechanical failure has decreased noticeably over the past 40 years, the rate attributable at least in part to human error has declined at a lower rate (Shappell & Wiegmann, 2000).

There is a considerable amount of information in the news and on the World Wide Web concerning UAV accidents. Many of these reports have mentioned human error as a contributing factor in the accident. In an April 18, 1999, crash of a Predator in Bosnia, a UAV experienced aircraft icing and lost engine power. The UAV pilots performed recovery procedures but were unable to land the UAV safely. The accident report stated that the pilots' attention became too focused on the rarely encountered severe weather conditions; they lost control of the UAV and were unable to recover. The report also cited lack of communication between the two pilots during the emergency (Aerotech News, 1999).

In a November 2000 crash of a Northrop Grumman Corporation, U.S. Navy, UAV prototype of a vertical Take-off and Landing Tactical Unmanned Aerial Vehicle (VTUAV-P1), the investigation found that human error associated with damaged antennas was the primary cause (Program Executive Office - Strike Weapons and Unmanned Aviation, 2001).

Officials investigating a March 30, 2001, crash of a Predator determined the accident resulted from operator error. The Predator experienced icing conditions causing the pilot to lose control of the aircraft. The accident report stated that the pilot failed to immediately perform the required checklist steps for a failed pitot static system that uses air and static pressure to determine the UAV's altitude and airspeed (Air Combat Command News Service, 2001).

The above examples were presented to emphasize the presence of human error causal factors in UAV accidents. Other accidents not cited were determined to have environmental and/or materiel failure causes. In addition, some of the accidents cited above also had environmental and materiel failure as contributing factors.

One study attempted to explore human factors causes from a simulation point of view. Ferguson (1999) developed a stochastic simulation model of U.S. Navy pioneer UAV accidents, half of which were attributed in part to human error. Verifying the obvious conclusion that human factors mistakes significantly degrade mission readiness, the model was intended to perform follow-up investigations of "intervention strategies" to address operator actions, hazardous flight conditions, and poor supervision.

It is a characteristic of human beings (pilots) to make mistakes (Southern California Safety Institute, 2002). If these mistakes lead to accidents, it is important to understand the nature of these mistakes. "Pilot error" is often given as the reason for an accident. However, human error almost always has underlying causes, which are often the real reason for an accident. These causes can include high (or low) workload, fatigue, poor situational awareness, inadequate training, lack of crew coordination, and poor ergonomic design. One or all of these causes can degrade performance, leading to accidents. The exocentricity (e.g, tele-operated), complexity, and mental workload of UAVs create a unique environment for the interaction of human and machine. This investigation of the role of human error in Army UAV accidents will analyze these accidents for the presence of these causes; therefore, it is important to understand the relationship of each of these causes to accidents.

Workload

Workload can be defined as the combination of task demands and human response to these demands (Mouloua et al., 2001a). UAVs, depending on whether they are semi-autonomous drones or RPVs, can produce a range of workload levels. Semi-autonomous and remotely piloted vehicles (RPVs) can present operators with long periods of low workload, which can be interspersed by periods of high workload during normal operation. During periods of malfunction, intense periods of high mental workload can be encountered. Wickens and Dixon (2002) studied 18 RPV pilots in a simulation environment that included auditory signals. The

tasks included navigation, target detection, and monitoring system displays. Findings revealed "considerable interference" between tasks.

Hancock and Warm (1989) have suggested that an operator using a system that presents long periods of inactivity can experience "vigilance-based stress." They use as examples tasks associated with UAVs such as visual scanning of displays and running computer-assisted diagnostics. Such tasks require constant attention from the operator—attention that degrades with time. An often-cited example is World War II radar operators who, after only minimum duty time, failed to detect incoming targets (Davies and Parasuraman, 1982). The factor of workload and its possible contribution to an accident must be investigated from the viewpoint of both high and low workload levels.

Vigilance can be affected by complacency (Prinzel, 2002). Defining complacency as a state of self-satisfaction that lowers the level of vigilance, Prinzel (2002) investigated the interaction of complacency and use of automated systems and possible pilot workload strategies. Findings showed that subjects with a higher desire to successfully complete the tasks were able to endure higher workloads.

Fatigue

Today's Army is one in which soldiers are subjected to rapid deployment across multiple time zones and unusual work periods, while requiring immediate and continuous performance. A recognized problem in achieving this goal is fatigue. Fatigue is defined as the state of feeling tired, weary, or sleepy that results from extended periods of mental or physical work, prolonged periods of anxiety, exposure to harsh environments, or loss of sleep (Comperatore, Caldwell, and Caldwell, 1997).

The human body uses sunrise and sunset to maintain a consistent internal association of physiological functions. Peak levels of physiological rhythms are specifically timed to occur at the appropriate phase of the daily day/night cycle (Comperatore and Krueger, 1990). Krueger (1999) discussed the special conditions based on soldiers who work during the night and rest during the day and often accumulate considerable sleep debt. He reports that continuous periods of workload add to fatigue, especially after multiple periods of total sleep loss or longer periods of reduced or fragmented sleep. This degrades performance, productivity, safety, and mission effectiveness. This sleep loss combines with workload to reduce reaction time and decrease vigilance. Caldwell et al. (2000), in a survey of 241 Army aviators and 120 Army enlisted crewmembers, found clear operational evidence that insufficient and/or inadequate sleep quality was adversely affecting on-the-job alertness.

Another study (Ramsey and McGlohn, 1997) that investigated fatigue as a safety factor reported that approximately 25 percent of the Air Force's night fighter Class A accidents between 1974 and 1992 and 12 percent of U.S. Navy Class A accidents from 1977 to 1990 were attributable to aircrew fatigue. Statistics from the USASC showed that 4 percent of the Army's total accidents (Class A, B, and C) from 1990 to 1999 were fatigue-related (Caldwell et al., 2000).

Rosekind et al. (1994) performed a rigorous search of the literature and concluded there are four fundamental factors that define fatigue and are important to accident investigation. These factors are: 1) sleep (acute loss and cumulative debt), 2) continuous hours of wakefulness, 3) circadian rhythms (time-of-day), and 4) sleep disorders.

Situational awareness

Army UAVs are remotely piloted. This places the pilots (operators) in a situation where they are flying the UAV exocentrically (remotely at distances of 1-200+ miles). This increases the complexity of staying aware of the UAV's surroundings and status. Having "a perception of the elements in the environment within a volume of space and time, the comprehension of their meaning, and the projection of status in the near future" is the meaning of having situational awareness (Endsley, 1988).

Situational awareness has consistently been a leading causal factor in military aviation mishaps (Hartel, Smith and Prince, 1991). Endsley (1999) established three levels of failure associated with reduced situation awareness:

- Level 1 – Failure to correctly perceive information.
- Level 2 – Failure to correctly integrate or comprehend information.
- Level 3 – Failure to project future actions or state of the system.

A study by Barnes and Matz (1998) looking at errors in simulated UAV flights found degraded situational awareness to correlate with frequency of operator errors. A contributing factor to poor situational awareness is the delay in commands and information between the operator and the UAV system. Such signal transmission delays can be one second or more and can introduce "temporal and spatial uncertainties" for the operator (Mouloua et al., 2001b). Wickens (1992) has shown that delays of one second or more can lead to significant errors. With delays between input and feedback, the operator's responses and commands can result in total loss of control of the vehicle.

Training

Operating UAVs and performing the associated tasks require training just as with any other Army system. High standards of training instill operator confidence (International Federation of Air Traffic Controllers' Associations, 2003). Inadequate training leads to accidents and, for that reason, is often a major component of accident models (Weiss et al., 2001). Elements of an effective training program include the use of experienced, well-trained instructors, well-defined program standards, and a good evaluation process (Education Commission of the States, 2000).

Crew coordination

UAV crews have similarities with manned aircraft crews. One important similarity is the necessity for good crew coordination. The Army defines crew coordination as a set of principles, attitudes, procedures, and techniques that transform individual pilots into an effective

crew (Giffin, 2003). The Army has stated that the lack of good crew coordination continues to be a contributing factor to Army aviation accidents (Giffin, 2003). Achieving good crew coordination requires eight elements: Communicating positively, directing assistance, offering assistance, announcing actions, acknowledging actions, being explicit, providing aircraft control and obstacle advisories, and coordinating action sequences and timing (Katz, 2001).

Ergonomic design

The last human factors cause to be included in this study is ergonomic design. Ergonomics is generally accepted to mean fitting the person to the job and fitting the job to the person (The Ergonomics Society, 2003). As used in this study, it pertains to fitting the operator to the control station. A good ergonomic design of the UAV operator station includes attention to such features as the displays, seating design and configuration, control layout, input devices (e.g., buttons, switches, etc.), and communication methods. While not downgrading the effect of the other features, special attention must be paid to the displays, since they are often the primary source of UAV situational awareness for the operator(s). In a paper looking at the ergonomics of UAV mission success, Mouloua et al. (2001b) discussed the massive amounts of information necessary for UAV operation and, noting the human limitation in processing such massive information, stated that selected displays must ensure that data presentation be in such a manner as to allow for efficient interpretation. Such displays must have operating characteristics that overcome viewing conditions such as ambient lighting and viewing angle.

Methods

This study was based on data obtained from the U.S. Army Risk Management Information System (RMIS) maintained by the USASC, Fort Rucker, AL. The Army investigates UAV accidents as ground accidents, versus aviation accidents. However, discussions are underway to reverse this position.

Accidents are classified as Class A, Class B, Class C, or Class D (Table 2). Accident data are provided per fiscal year (FY) (1 October through 30 September). Accident data used in this paper were based on a search for the period FY95-FY03, based on data entries made as of 12 February 2003. The first recorded UAV accident was on 30 January 1995. The search found a total of 56 UAV accidents.

Each accident was reviewed and classified by a series of characteristics. These included data regarding the UAV operators (e.g., age, gender, rank/grade, military occupational specialty (MOS), duty and flight status, number of hours on duty and sleep within the last 24 hours, indication of drug or alcohol use, etc.); accident class; environmental conditions at the time of the accident (e.g., visibility, presence of wind and precipitation, etc.); presence and type of any injury; type of UAV; type and cost of damage; and assignment of cause(s).

Analysis

Descriptive statistics were calculated for these characteristics. Where the assignment of cause included human error, the accident data including narrative and findings were analyzed to identify specific human causal factors (e.g., high/low workload, fatigue, poor crew coordination, etc.) using two approaches. The first was a variant on a methodology referred to as the Human Factors Analysis and Classification System (HFACS). The HFACS captures data for four levels of human-related failure (Shappell and Wiegmann, 2000): Unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences.

The four levels of human-related failure are expanded into 17 causal categories, which are depicted in Figure 2 (Shappell and Wiegman, 2001). The levels, categories, and subcategories are briefly described below with selective examples from Shappell and Wiegman (2000), which provide an expanded list of examples for each category.

The unsafe acts level is divided into two categories: Errors and violations. These two categories differ in "intent." Errors are unintended mistakes and are further categorized into skill-based errors, decision errors, and perceptual errors. Examples of skill-based errors include inadvertently leaving out an item on a checklist, failure to prioritize actions, and omitting a procedural step. Examples of decision errors include using the wrong procedure, misdiagnosing an emergency, and performing an incorrect action. Perceptual errors are those made due to the presence of visual illusions and spatial disorientation. Violations are willful errors. Examples include violating training rules, performing an overaggressive maneuver, and intentionally exceeding mission constraints.

The unsafe preconditions level is divided into two major categories: Substandard conditions of operators and substandard practices of operators. The substandard conditions of operators category is subdivided into three subcategories: Adverse mental states, adverse physiological states, and physical/mental limitations. Examples of adverse mental states include complacency, "get-home-itis," and misplaced motivation. Examples of adverse physiological states include medical illness and physical fatigue. Examples of physical/mental limitations include insufficient reaction time and incompatible intelligence/aptitude. The substandard practices of operators category is subdivided into two subcategories: crew resource management and personal readiness. Examples of crew resource management include failure to use all available resources and failure to coordinate. Examples of personal readiness are self-medication and violation of crew rest requirements.

The unsafe supervision level is divided into four categories: Inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisory violations. Examples of inadequate supervision include failure to provide training, failure to provide operational doctrine, and failure to provide oversight. Examples of planned inappropriate operations include failure to provide correct data, failure to provide sufficient personnel, and failure to provide the opportunity for adequate crew rest. Examples of failure to correct a known problem include failure to initiate corrective action and failure to report unsafe tendencies.

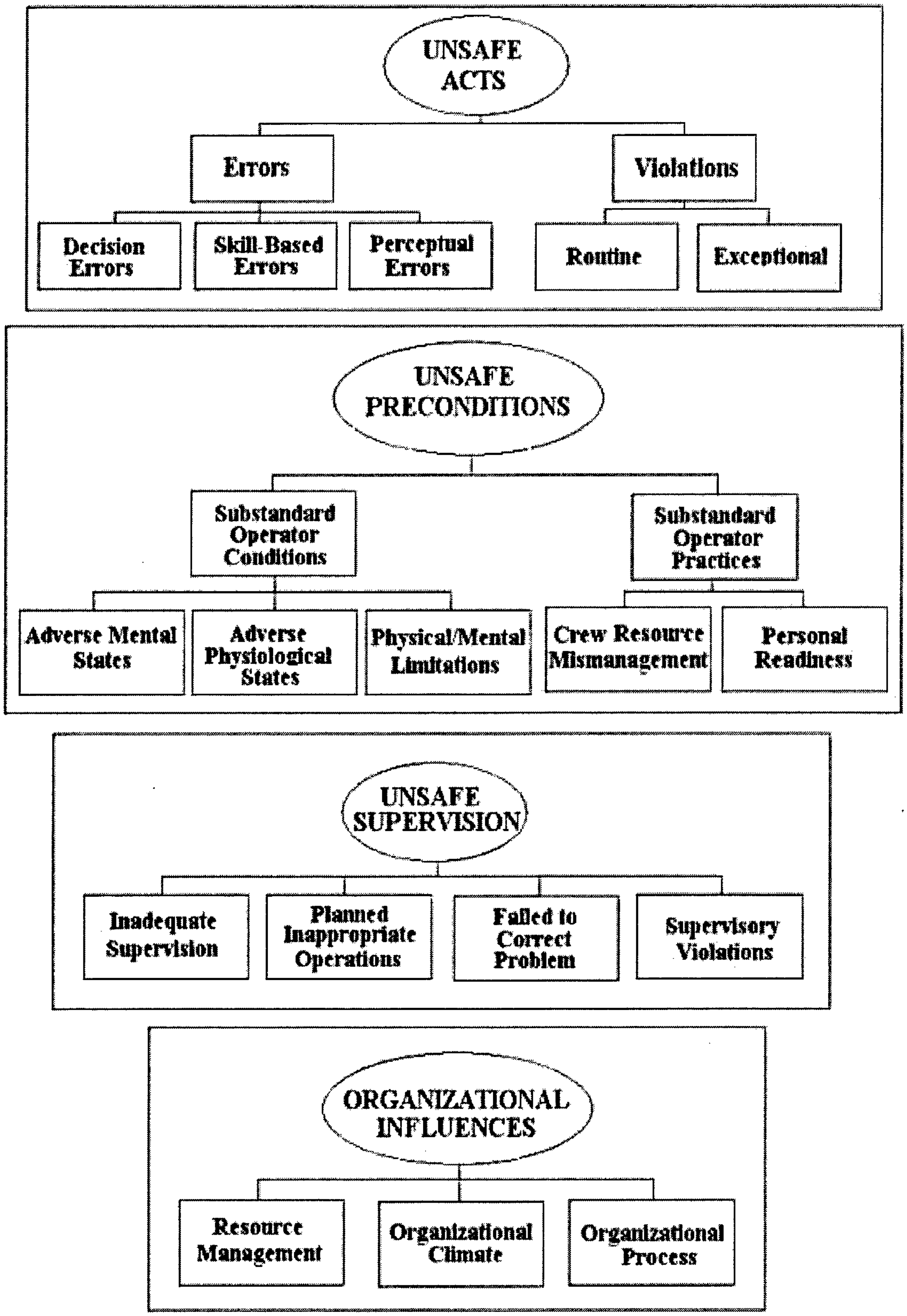


Figure 2. The 17 expanded HFACS categories (adapted from Shappell and Wiegmann, 2001).

Examples of supervisory violations include authorizing an unnecessary hazard and failure to enforce rules and regulations.

The organizational influences level has three categories: Resource/acquisition management, organizational climate, and organizational process. Examples of resource/acquisition management include lack of funding, poor equipment design, and insufficient manpower. Examples of organizational climate include policies on drugs and alcohol, value and belief culture, and chain-of-command structure. Examples of organizational process include quality of safety programs, influence of time pressure, and the presence or absence of clearly defined objectives.

The second analysis approach was based on the accident methodology defined in Department of the Army Pamphlet 385-40, "Army accident investigation and reporting." The Army uses a "4-W" approach to accident analysis that addresses the sequence of events leading to the accident. The "4-Ws" are: 1) When did error/failure/environment factor/injury occur? 2) What happened? 3) Why did it happen? 4) What should be done about it? Human causal factors are identified during this analysis and broken down into five types of failure: Individual failure, leader failure, training failure, support failure, and standards failure (Department of the Army, 1994b). These failure types are described as follows:

- Individual failure - when the soldier/individual knows and is trained to a standard but elects not to follow the standard (i.e., self-discipline--mistake due to own personal factors such as attitude, haste, overconfidence, self-induced fatigue, etc.).

- Leader failure - when the leader fails to enforce known standards, make required corrections, or take appropriate action.

- Training failure - when the soldier/individual is not trained to a known standard (i.e., insufficient, incorrect or no training on the task--insufficient in content or amount).

- Support failure - when there is inadequate equipment/facilities/services in type, design, availability, condition, or when there is an insufficient number/type of personnel, and these deficiencies contribute to human error.

- Standards failure - when standards/procedures are not clear or practical, or do not exist.

Table 2.
Army accident classes (Department of the Army, 1994b).

Class A	Class B	Class C	Class D
An accident in which the resulting total cost of property damage is $1,000,000 or more; an Army aircraft or missile is destroyed, missing, or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability.	An accident in which the resulting total cost of property damage is $200,000 or more, but less than $1,000,000; an injury and/or occupational illness results in permanent partial disability, or when three or more personnel are hospitalized as inpatients as the result of a single occurrence.	An accident in which the resulting total cost of property damage is $20,000 or more, but less than $200,000; a nonfatal injury that causes any loss of time from work beyond the day or shift on which it occurred; or a nonfatal occupational illness that causes loss of time from work or disability at any time.	An accident in which the resulting total cost of property damage is $2,000 or more but less than $20,000.

Both the HFACS and the Army's DA PAM 385-40 methods were applied to the accident data; then, frequencies and percentages of accidents meeting the respective criteria for failures were calculated.

Results

Accident demographics

The purpose of this study was to analyze UAV accidents to identify those with human causal factors. There were 56 UAV accidents reported in the USASC's accident database for the period FY95-FY03. No consistent nomenclature was used in the identification of UAV types involved in the accidents. Identification ranged from precise models (e.g., RQ-5 Hunter and RQ-7 Shadow) to general terms such as "drone," "trainer," and "UAV." Of the 56 vehicles, 17 were clearly identified as the RQ-5 Hunter and 10 as the RQ-7 Shadow.

There was approximately an equal number of Class B and Class C accidents, 22 (39%) and 23 (41%), respectively. Eight accidents (14%) were Class D; only 3 (5%) were Class A. The total cost assigned to these accidents was $13,785,088, with an accident average of $246,162. The majority of accidents (79%) occurred during daytime hours. Only 4 accidents (7%) were recorded as combat accidents; all accidents were considered to be training in nature.

Unfortunately, there were considerable omissions in the accident reports regarding demographic data on the UAV operators associated with the accidents. Age data were available for only 35 of the 56 operators; only 39 of 56 for gender data; and only 40 of 56 for personnel classification data. However, for the data that were provided, the operator age ranged from 20 to 55 years, with a mean and standard deviation of 30.3 and 10.7 years, respectively. Operators were mostly male (64%) and Army personnel (54%). See Table 3 for a summary of UAV operator demographic data. [Note: The operator was not the only human involved in the accidents. Supervisors, support personnel, and bystanders also were involved. However, demographic data, when present, were recorded for the operator only.]

Table 3.
UAV operator demographics.

Age (Years)				
Min	Max	Mean	Median	SD
20	55	30.3	28	10.7

Gender		
Male	Female	Unknown
36 (64%)	3 (5%)	17 (30%)

Personnel classification			
Army	DAC	Contractor	Unknown
30 (54%)	1 (2%)	9 (16%)	16 (29%)

Accident data regarding injury were available on all but two accidents, and only two (4%) of the accidents reported injuries. In one accident, a drone was being recovered following a flight, the data link was lost, and the drone crashed into the metal doors of a building. An individual working inside the building was startled by the crash and moved quickly to take cover behind a vehicle. Although initially reporting no injury, the individual later sought medical attention and reported having a fractured hip. In the other accident, the UAV's right wing struck the external flight control box stand causing minor cuts and lacerations to the Army student operator.

Two blocks on the accident reporting form (Department of the Army Form 285) address the number of hours the operator had been on duty prior to the accident and the number of cumulative hours of sleep the operator reported having within the previous 24 hours. For the hours on duty block, valid responses were considered to be present for only 35 of the 56 accidents. Based on these valid responses only, the range was 0 to 12 hours, with a mean and standard deviation of 5.2 and 2.6 hours, respectively. A similar problem with recorded data existed for the hours of sleep block. Based on 33 valid responses, the range was 0 to 10 hours, with a mean and standard deviation of 7.9 and 0.8 hours, respectively. [Note: Eleven accidents reported 0 hours for both blocks. These were considered invalid responses, since all but four accidents were in a training environment, and a report of zero hours sleep seemed unlikely.]

The recording in the accident report of drugs and alcohol being used by the operator was available in only 36 of the 56 accidents; all provided responses were negative. Three blocks on the accident form report the causal factors assigned to the accident. One block addresses human

error by asking the question, "Did the individual make a mistake (Y/N)?" Another block addresses environmental contributions by asking if environmental conditions caused/contributed to the accident? The remaining block addresses materiel failure by asking the investigator to explain, "How the materiel failed/malfunctioned/contributed" to the accident? It is possible for more than one of the blocks to be completed. Data in more than one of the blocks imply both root and contributing causes. In rare cases, the cause(s) may be undetermined.

Table 4 represents the distribution of the 56 UAV accidents by causal factor category, as designated on the accident reports and in the USASC RMIS. The most common sole accident causal category was materiel failure (32%). Human error was designated as the sole causal factor in 11 percent of all accidents and as the sole or one of a combination of contributing factors in 32 percent of all accidents. Of the three causal factor categories, environmental was the least frequently present, in only 4 of the 56 accidents (7%); it was the sole factor category in only 5 percent of all accidents.

Seventeen accidents were categorized as "Undetermined." Two of the undetermined accidents occurred very recently (FY03), and investigators have not had sufficient time to complete the accident investigation. However, a number of the other undetermined accidents also have incomplete accident reports, even after periods exceeding several years.

Table 4.
Summary of accidents by causal factors.

Causal factor(s)	Frequency	Percent
Materiel failure	18	32
Environment	3	5
Human error	6	11
Materiel failure & human error	6	11
Environment & human error	5	9
Materiel failure & environment	0	0
Materiel failure & environment & human error	1	2
Undetermined (or left blank)	17*	30
Total	56	100

* Includes two FY03 accidents that are awaiting final determination.

HFACS analysis

The application of the HFACS analysis approach identified 18 of the 56 UAV accidents (32%) as involving human error, either as the sole causal factor or as one of a combination of contributing causal factors. Table 5 presents the breakdown of these 18 accidents by HFACS causal factor categories. A more detailed description of the causal factors and the rationale for identification as specific categories are presented in Appendix A. Based on all 56 accidents, the most represented HFACS category was "Unsafe acts" (20%). The second most prevalent HFACS category was "Unsafe supervision" (16%).

Table 5.
UAV accidents associated with each HFACS causal category.

HFACS category	Frequency of occurrences	Accidents	Percentage* based on all 56 accidents	Percentage* based on 18 human error accidents
Unsafe acts	16	11	20	61
Skill-based errors	4	4	7	22
Decision errors	6	6	11	33
Perceptual errors	3	3	5	17
Violations	3	2	4	11
Preconditions for unsafe acts	1	1	2	6
Crew resource management	1	1	2	6
Unsafe supervision	11	9	16	50
Inadequate supervision	6	6	11	33
Failed to correct known problem	3	3	5	17
Supervisory violations	2	2	4	11
Organizational influences	8	8	14	44
Organizational process	8	8	14	44

*Note that the percentages will not add up to 100% because accidents are typically associated with more than one causal factor.

When just the 18 accidents involving human error were considered, "Unsafe acts" were present in 61 percent, and "Unsafe supervision" was present in 50 percent of these accidents. "Organizational influences" and "Preconditions for unsafe acts" were present in 44 percent and 6 percent of the human error accidents, respectively.

Within the major HFACS category of "Unsafe acts," four subcategories were identified: Skilled-based errors, decision errors, perceptual errors, and violations. The most common unsafe act was decision errors, present in 11 percent of all accidents and 33 percent of all human error accidents. Incidents of decision errors included: a) when the external pilot hurried turns using steep angles of bank, preventing a proper climb rate, which resulted in a crash, and b) when the wrong response to an emergency situation was made by commanding idle power after the arresting hook had already caught on the arresting cable. All incidents of "Unsafe acts " are fully described in Appendix A.

The single accident categorized as "Preconditions for unsafe acts" was further identified as a crew resource management issue. The accident report stated that poor coordination between student and instructor was present.

Three subcategories were identified under "Unsafe supervision:" Inadequate supervision, failed to correct a known problem, and supervisory violations. The most common "Unsafe supervision" subcategory was inadequate supervision, present in 11 percent of all accidents and 33 percent of human error accidents. Incidents of inadequate supervision included: a) failure to provide training for the UAV operator on effects of wind, and b) failure to provide proper monitoring of contract personnel to ensure adequate inspections/checks. All incidents of "Unsafe supervision" are fully described in Appendix A. Note: HFACS uses a more generalized definition for the terms "supervisor" and "supervision" than is used by the Army, encompassing any individual, at any level, who has the authority to make a decision.

All of the accidents identified under "Organizational influences" fell under one subcategory: Organizational process. Incidents under this subcategory included: a) failure to maintain training records, and b) lack of written guidance on inspection and replacement criteria. All incidents of "Organizational influence" are fully described in Appendix A.

DA PAM 385-40 analysis

The second analysis approach applied to the UAV accidents was that defined in Department of the Army Pamphlet 385-40, which characterizes accidents by five categories of failures: Individual, leader, training, support, and standards. The application of the Army analysis identified 18 out the 56 UAV accidents (32%) as involving human error, the same accidents identified by the HFACS analysis.

Table 6 presents the breakdown of these 18 accidents by DA Pam 385-40 causal factor categories. A more detailed description of the causal factors and the rationale for identification as specific categories are presented in Appendix B.

Based on 56 accidents, the most represented Army failure was "Individual failure" (20%). The second most prevalent failure category was "Standards failure" (14%). When just the 18 accidents involving human error are considered, "Individual failure" was present in 61 percent, and "Standards failure" was present in 44 percent of these accidents. "Leader failure," "Training failure," and "Support failure" were present in 33 percent, 22 percent, and 6 percent of the human error accidents, respectively.

Incidents of "Individual failure" included: a) operator misjudged wind conditions during landing, and b) crew members overlooked improperly set switch on control box. Incidents of "Leader failure" included: a) a crewmember who did not have a current certification of qualification was assigned as an instructor pilot (IP), and b) leadership failed to provide oversight of placing UAV in tent and having tent properly secured. Incidents of "Training failure" included: a) training was not provided to the UAV operator on effects of wind, and b) training was not provided on single engine failure emergency procedures. There was only one incident of "Support failure," which was that a contractor did not take appropriate maintenance actions even though information was available. Incidents of "Standards failure" included: a) written checklist procedures for control transfers were not established in the TM, and b) there was no written guidance on inspection and replacement criteria for the clutch assembly. All incidents of the various failure categories are fully described in Appendix B.

Table 6.
UAV accidents associated with each Army causal category.

Army category	Frequency of occurrence	Accidents	Percentage* based on all 56 accidents	Percentage* based on 18 human error accidents
Individual failure	11	10	20	61
Leader failure	6	6	11	33
Training failure	4	4	7	22
Support failure	1	1	2	6
Standards failure	8	8	14	44

*Note that the percentages may not add up to 100% because accidents are typically associated with more than one causal factor.

Comparison of analyses findings

Both analyses identified the same 18 accidents involving human error. It is useful to compare the findings of the two analyses. While there is no one-to-one correspondence between the categories defined by the two analyses, the author proposes an association depicted by the relationships in Figure 3. The proposed relationships loosely correlate the HFACS categories of

"Unsafe acts" and "Preconditions for unsafe acts" with "Individual failure;" Unsafe supervision" correlates with "Leader failure" and "Training failure;" and "Organizational influences" correlates with "Support failure" and "Standards failure."

When accident proportions are grouped according to the proposed relationships of causal factor categories (Table 7), they are approximately equal. Considering the small number of accidents involved, this finding would seem to strongly support the proposed association of causal categories in Figure 3.

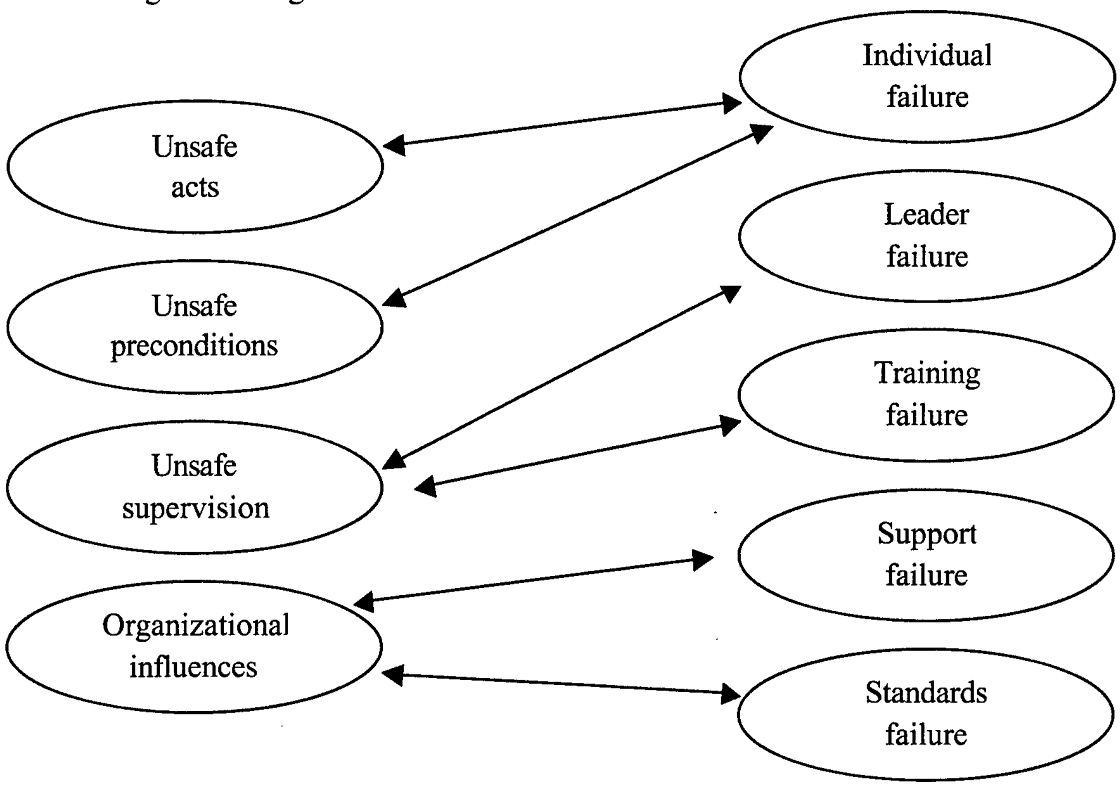


Figure 3. Suggested relationships between the HFACS and DA PAM 385-40 categories.

Table 7.
Accident proportions by grouped relationships.

HFACS categories	*Sum of HFACS	*Sum of PAM 385-40	PAM 385-40 categories
Unsafe acts Preconditions for unsafe acts	61%	55%	Individual failure
Unsafe supervision	50%	44%	Leader failure Training failure
Organizational influences	44%	44%	Support failure Standards failure

*Percentages exceed 100% because any given accident may have multiple causal factors.

Discussion

Summary

While UAVs are not currently expected to replace manned vehicles, they do provide an alternative to putting soldiers in harm's way. If UAVs are to be an effective replacement, they must meet or exceed levels of mission effectiveness currently achieved by manned vehicles and be cost effective, as well. The primary method to meet these goals is by reducing accident frequency through a thorough understanding of causal factors. Since human-related causal factors have historically been present in a significant proportion of accidents, it is the goal of this study to investigate the role these factors play in Army UAV accidents. Two methods of analyzing accidents were applied to the 56 UAV accidents. As a result, a number of human causal factors and the distribution of their occurrence in these accidents were revealed.

Human error plays a major role in U.S. Army UAV accidents. For the period FY95-FY03, human error is present in approximately one-third (32%) of all UAV accidents. No single human causal factor is responsible for all accidents. However, both methods of analysis identify individual unsafe acts or failures as the most common human-related causal factor category (present in approximately 61% of the 18 human error related accidents). Failure to develop and enforce policies and standards is also a leading causal factor category and contributes to almost half of the accidents involving human error. Leadership (or supervision) is an equally significant factor, present in 33 percent (DA PAM 385-40) to 50 percent (HFACS) of human error accidents. Each method also reveals that all of the major causal factor categories contribute to accidents, with approximately half of the human-error accidents involving two or more of the causal factor categories.

The author-proposed association between the different major causal factor categories (Figure 3) shows an almost total agreement for the proportions of accidents across the HFACS and DA PAM 385-40 categories. However, the HFACS method provides significantly greater detail in the types of human error present in the accidents. Because of this greater definition, HFACS helps identify more specific types of human error. For example, while in agreement with the Army's proportion of accidents involving "Individual failure," the HFACS analysis further separates the comparable "Unsafe acts" category into four subcategories: Skill-based errors, decision errors, perceptual errors, and violations. Decision error is identified as the most frequent individual act or failure, present in 6 of the 11 accidents under the "Unsafe acts" category.

Implications

In showing that human-error plays as significant a role in UAV accidents as in virtually all types of accidents, this study is a reminder to the Army that safety programs are as important in UAV operations as in all other operations. The identification of individual unsafe acts or failures as a leading human-related causal factor in these accidents implies the need for emphasis on safety programs that target individual mistakes.

Recommendations

The predominant means of investigating the causal role of human error in all accidents remains the analysis of post-accident data (Wiegmann and Shappell, 1999). As has been demonstrated in this study, the Army's current accident reporting and analysis method does not allow the straightforward capture of detailed human error accident data. While realizing that the redesign of accident investigation procedures, forms, and databases is not an easily undertaken task, it is recommended that the USASC coordinate with the UAV training center at Fort Huachuca, Arizona, to coordinate modification or supplementation of existing accident investigation methods to address human error data collection deficiencies.

To help develop more focused, and therefore more effective, training programs that will address human error in UAV accidents, an analysis methodology such as provided by HFACS is needed to extract detail in causal factors. This study shows that such training programs need to address all of the major causal factor categories, with special attention on the prevention of individual errors or failures.

However, the implementation of any augmented accident data collection method is only useful if investigators conscientiously collect the necessary data. As has been seen in this study, a significant number of data parameters, many of which are believed by the authors to be readily available, are not being recorded. Therefore, it is further recommended that the Army, down to the unit level, place command emphasis on the training of investigators, emphasizing the need for, and the importance of, conscientious recording during accident investigations. Due to the relatively small number of accidents available for this study, it is recommended that the study be repeated when more data are available.

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Appendix A.

HFACS detailed accident analysis.

Accident #	Causal factors
1	• HFACS-1 Unsafe acts/Errors/Skill-based error/Omitted checklist item--Did not reset the arresting gear system in accordance with Technical Manual (TM). • HFACS-1 Unsafe acts/Errors/Decision error/Misdiagnosed wind conditions--Did not properly judge wind conditions. • HFACS-3 Unsafe supervision/Inadequate supervision/Failed to provide training--Recommendation to conduct training of UAV operator on effects of wind. • Note: Operator and support personnel involved.
2	• HFACS-3 Unsafe supervision/Inadequate supervision/Failed to provide training--Initial EP training does not include training for landing on runways under adverse weather conditions. • HFACS-4 Organizational influences/Organizational process/Standards--Standard not developed for external pilots (EPs) to establish proper landing zone for recovery of aircraft.
3	• HFACS-4 Organizational influences/Organizational process/Standards--The TM does not specifically direct the repairer to check the gear reduction box fluid level.
4	• HFACS-4 Organizational influences/Organizational process/Standards--EP's actions were result of inadequate written procedures for handoff.
5	• HFACS-1 Unsafe acts/Violation/Failed to adhere to brief--Contract personnel did not perform mission IAW government mission briefs and directives. • HFACS-3 Unsafe supervision/Inadequate supervision/Failed to provide oversight--Government employee-monitoring contractor failed to ensure adequate inspections/checks of the UAV were performed.
6	• HFACS-1 Unsafe acts/Errors/Perceptual errors/Misjudged perspective--Student did not adequately correct for the left drift of the vehicle, because of the perspective of the vehicle as it passes the EP station. • HFACS-3 Unsafe supervision/Supervisory Violation--Allowed student to exceed standard for takeoff. • HFACS-3 Unsafe supervision/Failed to correct known problem--failed to take corrective action--allowed student to continue to fly vehicle rather than taking control. • HFACS-3 Unsafe supervision/Inadequate supervision--failed to provide training. • HFACS-4 Organizational influences/Organization process/Procedures--Hunter standards.

7	• HFACS-1 Unsafe acts/Errors/Decision error--Failed to apply appropriate action in timely manner.
8	• HFACS-3 Unsafe supervision/Failed to correct known problem--Did not confirm dissemination of known safety of flight information to contractor. • HFACS-4 Organizational influences/Organization process/Procedures--Lack of written guidance on inspection and replacement criteria.
9	• HFACS-1 Unsafe acts/Errors/Skill-based error--Improperly set a switch. • HFACS-4 Organizational influences/Organizational process/Procedures--Written checklist procedures for control transfers are not established in TM.
10	• HFACS-3 Unsafe supervision/Inadequate supervision--Failed to provide oversight in making final checks of door. • HFACS-4 Organizational influences/Organizational process/Procedures--No procedures were available for handling situations where special payloads activities (other crews) interrupted the normal pre-launch checklist.
11	• HFACS-3 Unsafe supervision/Inadequate supervision--failed to provide oversight of placing UAV in tent and having tent properly secured.
12	• HFACS-1 Unsafe acts/Errors/Skill-based error--Poor technique in handling UAV descent.
13	• HFACS-1 Unsafe acts/Errors/Decision error--Slow to follow procedure. • HFACS-3 Unsafe supervision/Supervisory violation--Authorized unqualified operator for flight.
14	• HFACS-3 Unsafe supervision/Failed to correct known problem--Failed to address being able to keep pendant at proper height.
15	• HFACS-1 Unsafe acts/Errors/Decision error--EP hurried turns using steep angles of bank that prevented proper climb. • HFACS-1 Unsafe acts/Errors/Skill-based/Omitted checklist item to drop flaps. • HFACS-4 Organizational influences/Operational processes/Oversight--Failure to maintain and training records.
16	• HFACS-1 Unsafe acts/Errors/Perceptual Error--Corrective input was opposite of what was needed as the UAV approached him due to situation where control inputs appear to be opposite of those required as vehicle is approaching EP.

17	• HFACS-1 Unsafe acts/Errors/Perceptual Error/Visual illusion--Had a visual illusion of floating. • HFACS-1 Unsafe acts Errors/Decision error--Wrong response to emergency by commanding idle power after arresting hook caught.
18	• HFACS-1 Unsafe acts/Violation--Student executed changes to programmed database without approval/direct supervision and not following standard operating procedure (SOP). • HFACS-1 Unsafe acts/Violation--Failed to follow SOP for setting switches at end of shift. • HFACS-1 Unsafe acts/Errors/Decision error--Poor decision in that both operators and EP/instructor failed to pass on glide warning. • HFACS-2 Preconditions for unsafe acts/Substandard practice of operators/Crew resource management--Poor crew coordination between student and instructor.

Appendix B.

DA PAM 385-10 detailed accident analysis.

Accident #	Causal factors
1	• Individual failure--Misjudged wind conditions during landing. • Individual failure--Omitted checklist item (did not reset the arresting gear system in accordance with TM 9XXX-694019). • Training failure--Failure to provide training of UAV operator on effects of wind.
2	• Training failure--Training does not include training on landing on runways under adverse weather conditions. • Standards failure--No standard procedure to establish proper landing zone for recovery of aircraft.
3	• Standards failure--The TM does not specifically direct the repairer to check the gear reduction box fluid level.
4	• Standards failure--External Pilot's (EP) actions were the result of inadequate written procedures for handoff of UAV to backup EP.
5	• Individual failure--Contract personnel did not perform mission IAW government mission briefs and directives. • Leader failure--Government employee-monitoring contract failed to ensure adequate inspections/checks of the UAV were performed.
6	• Leader failure--Instructor failed to take corrective action, allowed student to continue to fly vehicle rather than taking control. • Training failure--There is no documented on-going training for EPs for UAV takeoff maneuver. • Standards failure--No formal procedures that establish operator workload, crew duties and responsibilities and standardized terminology for the Hunter UAV.
7	• Individual failure--Failed to apply appropriate action in timely manner during go-around.
8	• Support failure--Contractor did not take appropriate maintenance actions even though information was available. • Standards failure--lack of written guidance on inspection and replacement criteria for the clutch assembly.

9	• Individual failure--Crewmembers overlooked improperly set switch on control box. • Standards failure--Written checklist procedures for control transfers were not established in TM.
10	• Leader failure-- Failure to provide oversight in making final checks of door • Standards failure--No procedures were available for handling situations where special payloads activities (other crews) interrupted the normal prelaunch checklist.
11	• Leader failure--Leadership failed to provide oversight of placing UAV in tent and having tent properly secured.
12	• Individual failure--Poor technique in handling UAV descent by improper use of elevator inducing stall.
13	• Individual failure--Failed to follow engine-out procedure. • Leader failure--Assigned a crewmember as an IP who did not have a current certification of qualification.
14	• Standards failure--Failed to address being able to keep pendant at proper height on dirt runway.
15	• Individual failure-- EP hurried turns using steep angles of bank, which prevented proper climb; forgot to lower flaps during landing sequence. • Leader failure-- Failure to maintain training records; therefore was unable to determine lack of training of EP for handling single engine failure emergency procedures. • Training failure--Failed to provide training on single engine failure emergency procedures.
16	• Individual failure--Corrective input was opposite to what was needed as the UAV approached him due to situation where control inputs appear to be opposite of those required as vehicle is approaching EP.
17	• Individual failure-- Had a visual illusion of floating and applied improper emergency procedure; incorrectly applied idle power after engaging arresting hook causing a hard landing.
18	• Individual failure-- Student executed changes to programmed database without approval/direct supervision and not following SOP; failed to follow SOP for setting switches at end of shift; poor decision in that both operators and EP/instructor failed to pass on glide warning; poor crew coordination between student and instructor.